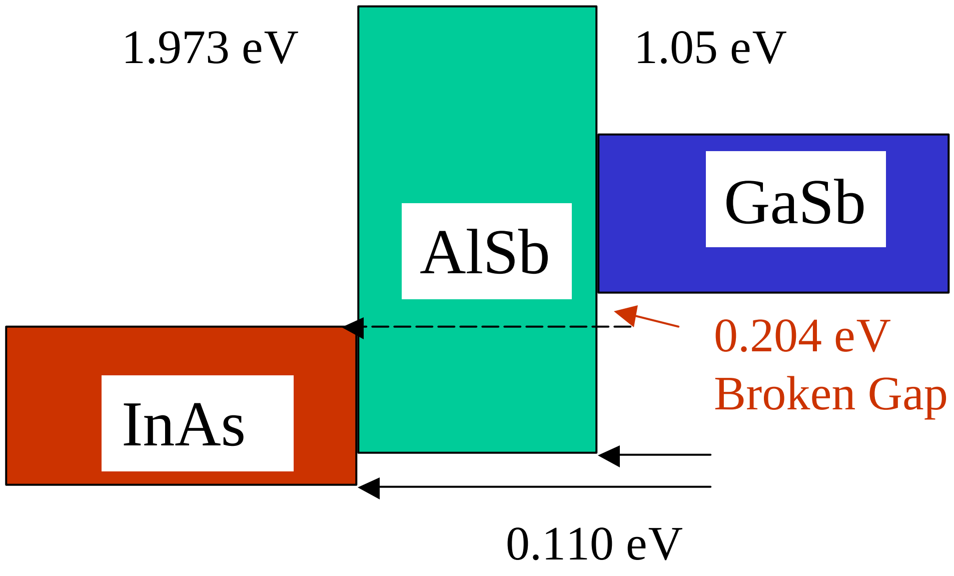
Crazy Ideas

T. C. McGill

Caltech

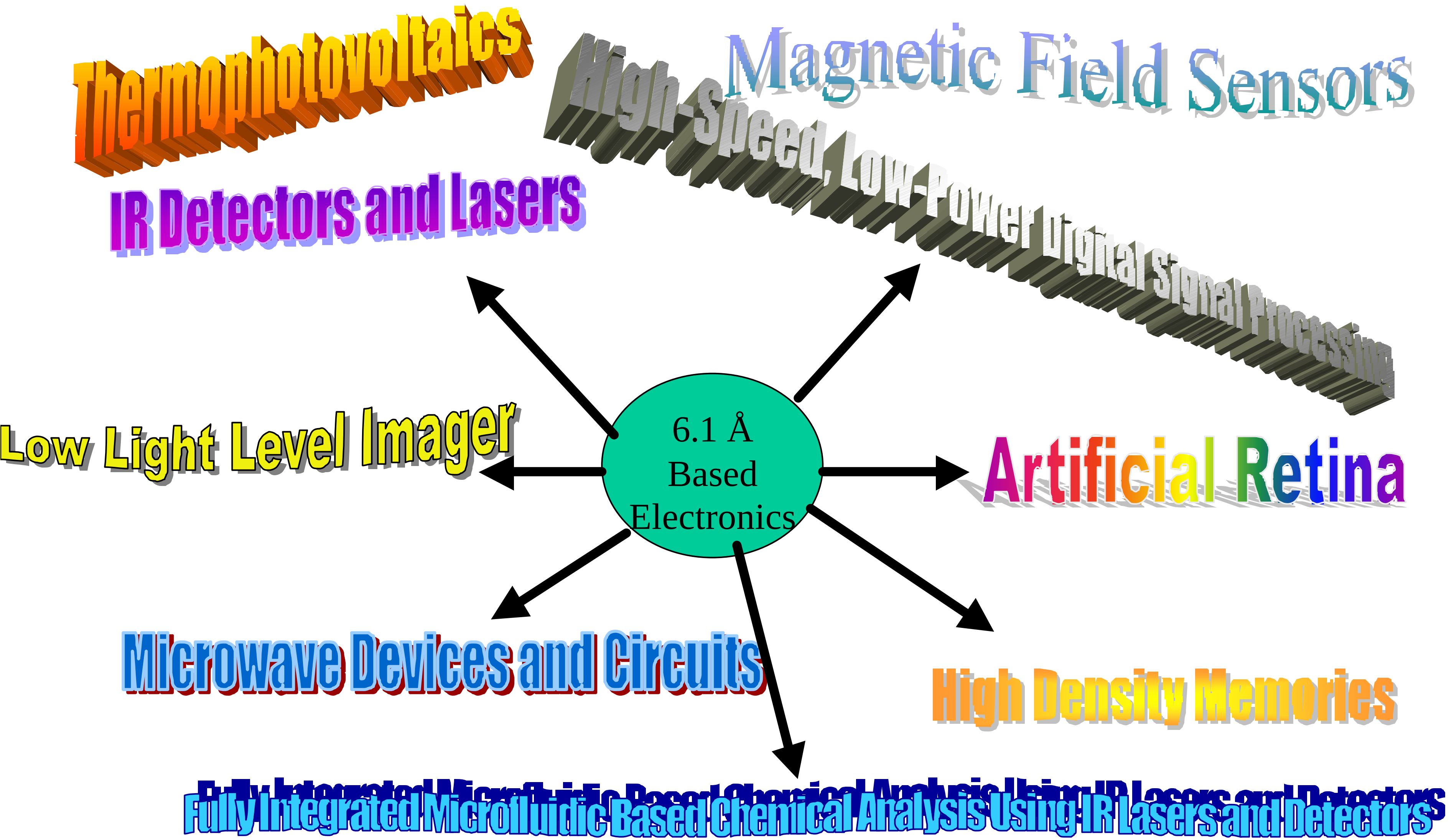
InAs/GaSb/AlSb Devices



Material	Band Gap (eV)	Lattice Constant (Å)
InAs	0.356	6.058
GaSb	0.70	6.095
AlSb	1.62	6.138

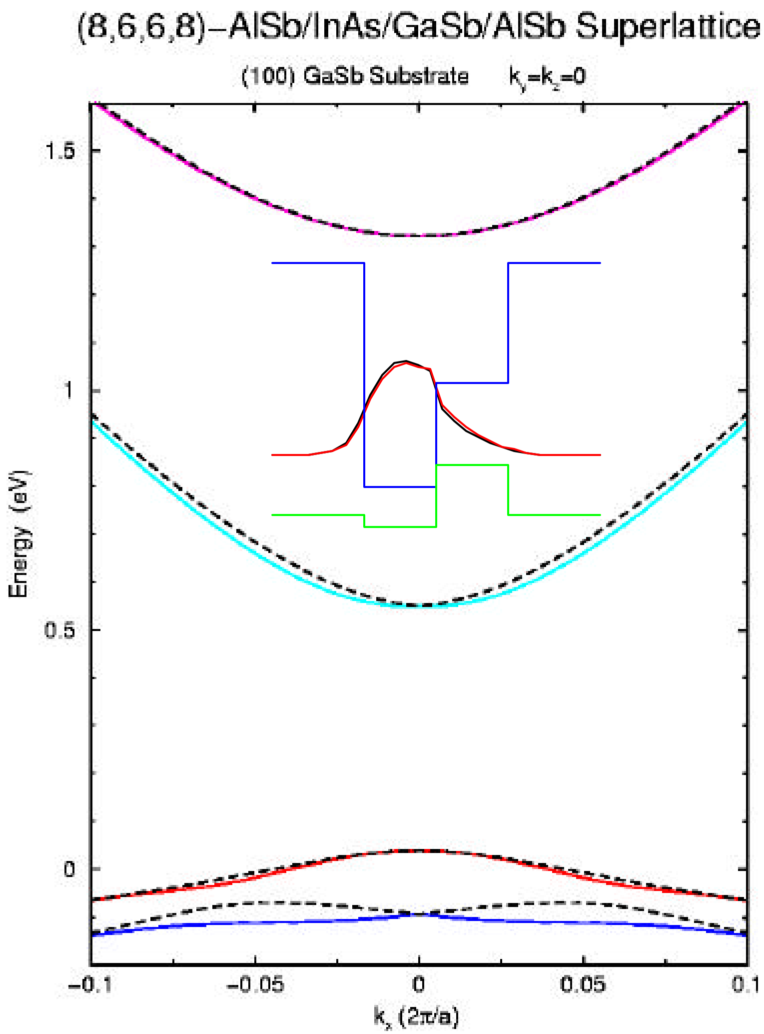
- InAs Very High Electron Mobilities
- Negative Schottky Barrier between n-InAs and Metals
- Unusual Band Lineups-Gives Lots of Unique Devices

6.1A Electronics: The Answer to Many of the Militaries Unique Needs



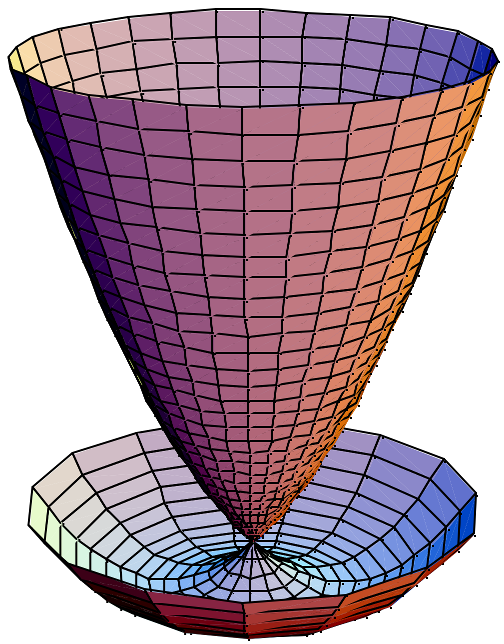
Brief reminder of Rashba effect basics

What is the Rashba effect



- In quantum wells with asymmetric walls, the states in the CB become spin split.
- InAs/GaSb/AlSb superlattice with highly asymmetric design.
- Electrons confined in InAs
- Removal of Krammer’s degeneracy results in spin splitting.
- Spin Splitting > 20 meV

2D Band Structure

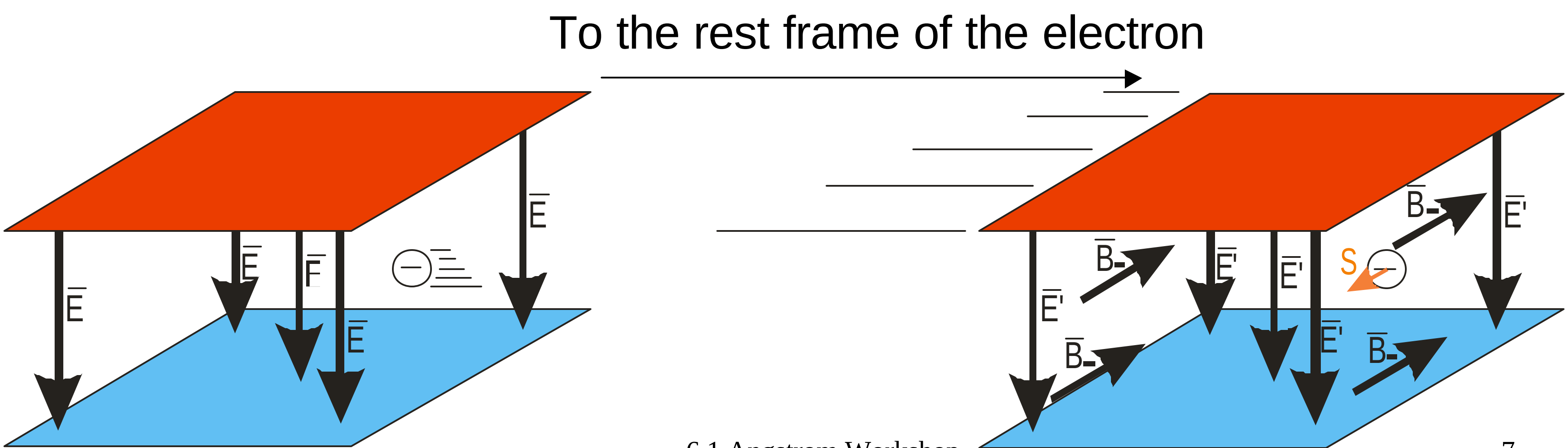


- The band structure near the zone center is a figure of revolution of the plot along the line.
- The bands only cross at the point.
- The minimum of the CB is no longer at the point, but in a circle close to it.

Physical origin of the phenomenon

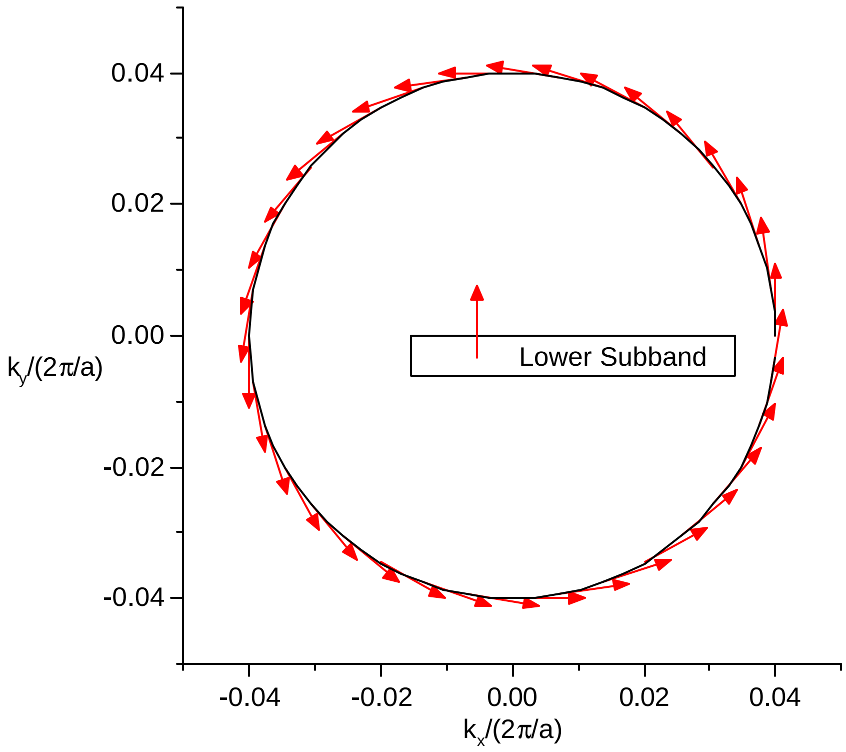
- In the absence of spin-orbit interaction, there is no reference in the Hamiltonian to spin; so the bands are spin degenerate. Therefore, spin-orbit coupling is a good candidate as the origin.

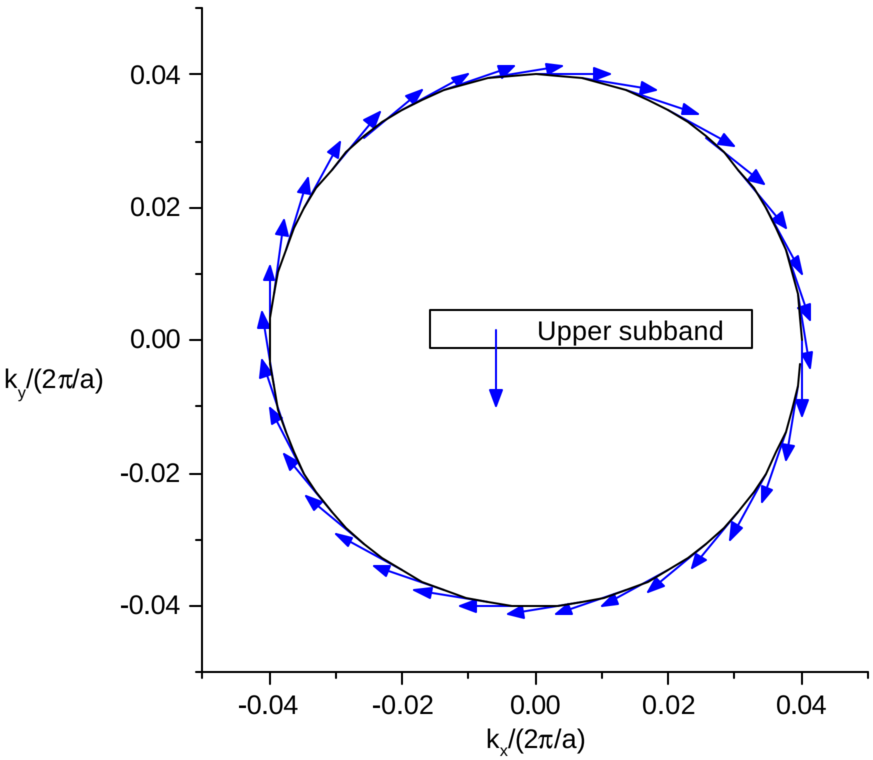
$$\vec{B}_{ef} = -\frac{1}{c^2}\vec{v}\times\vec{E}$$



Calculated spin direction

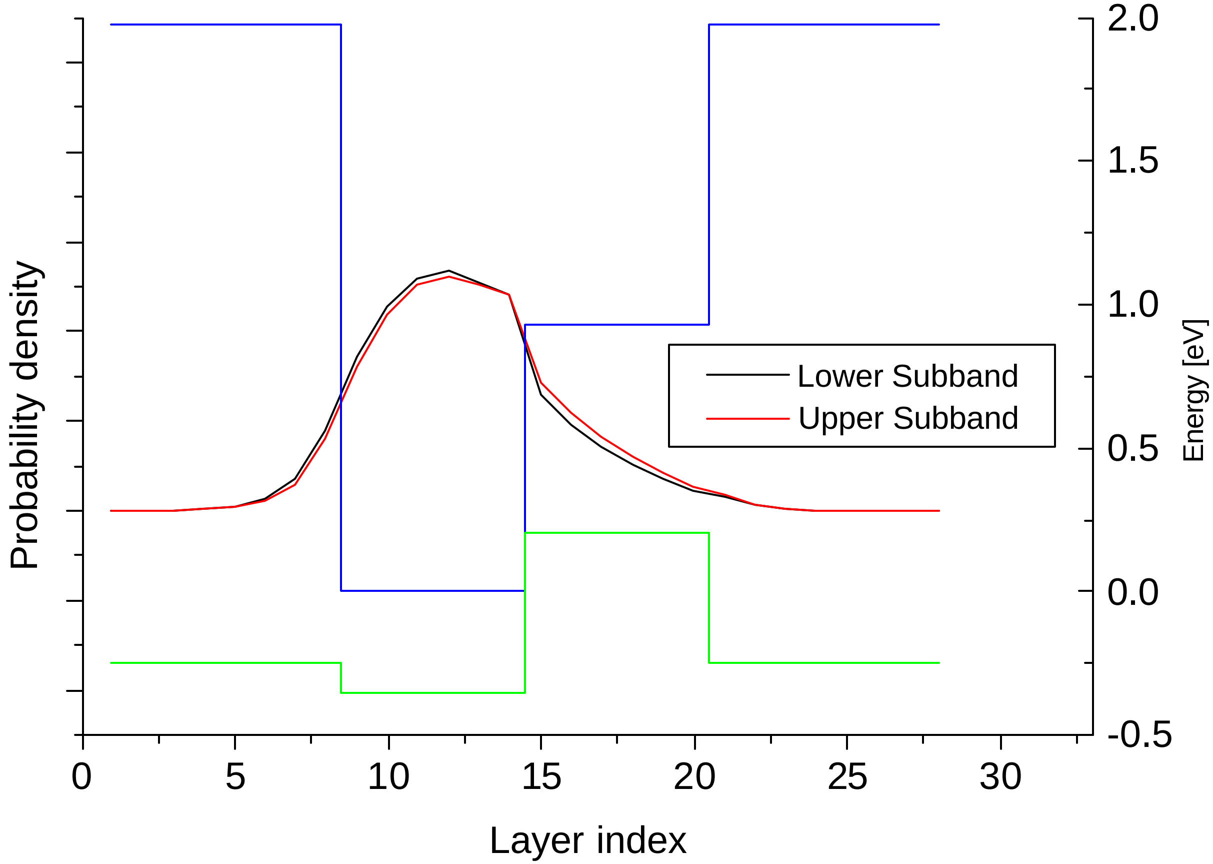
8 ML AlSb / 6 ML InAs/ 6 ML GaSb/ 8 ML AlSb superlattice





- Lower subband spins point counterclockwise.
- Upper subband spins point clockwise.

Effect on the wavefunction

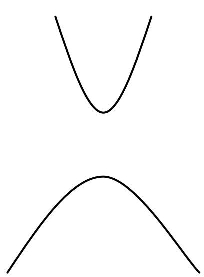


- States belonging to the lower subband are slightly biased towards the AlSb wall (the electron wants to be be in a place with lower energy), whereas upper subband states shift to the GaSb wall and layer.

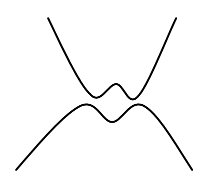
Exploration of parameter space

Exploration of parameter space

- We have performed a set of calculations of the Rashba coefficients for structures of the kind
- J InAs/ K GaSb / L AlSb J,K,L =1,2,…,30
- The effect is washed out when the structure is near symmetric.
- Effect drops dramatically when the InAs CB and the GaSb VB anticross:

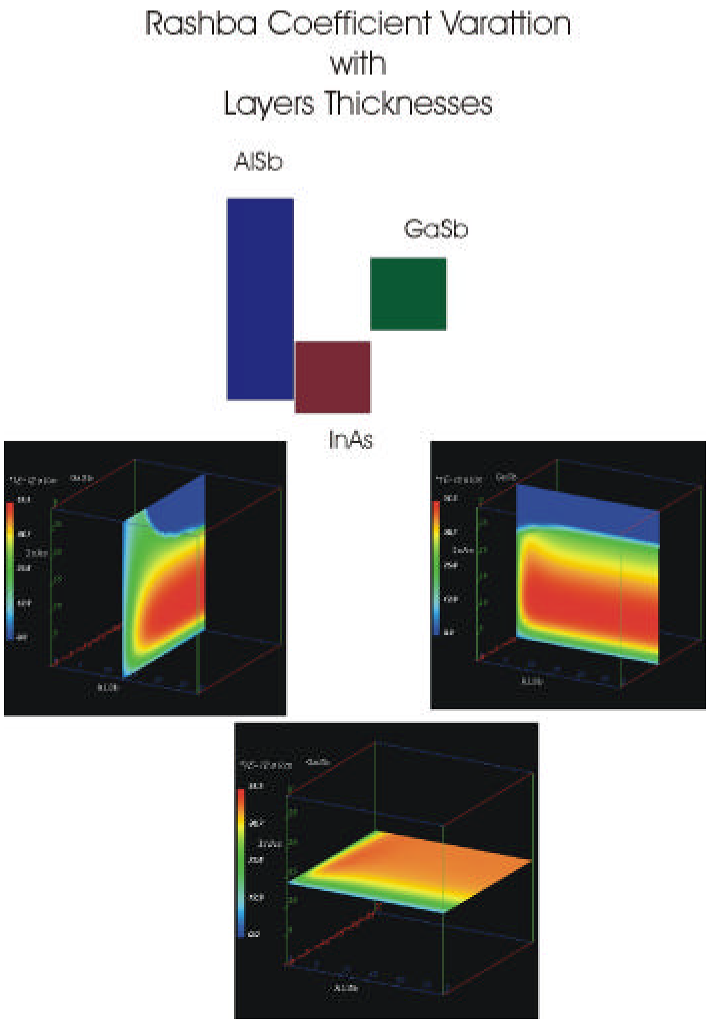


Big $_R$



Small $_R$

Rashba Coefficients

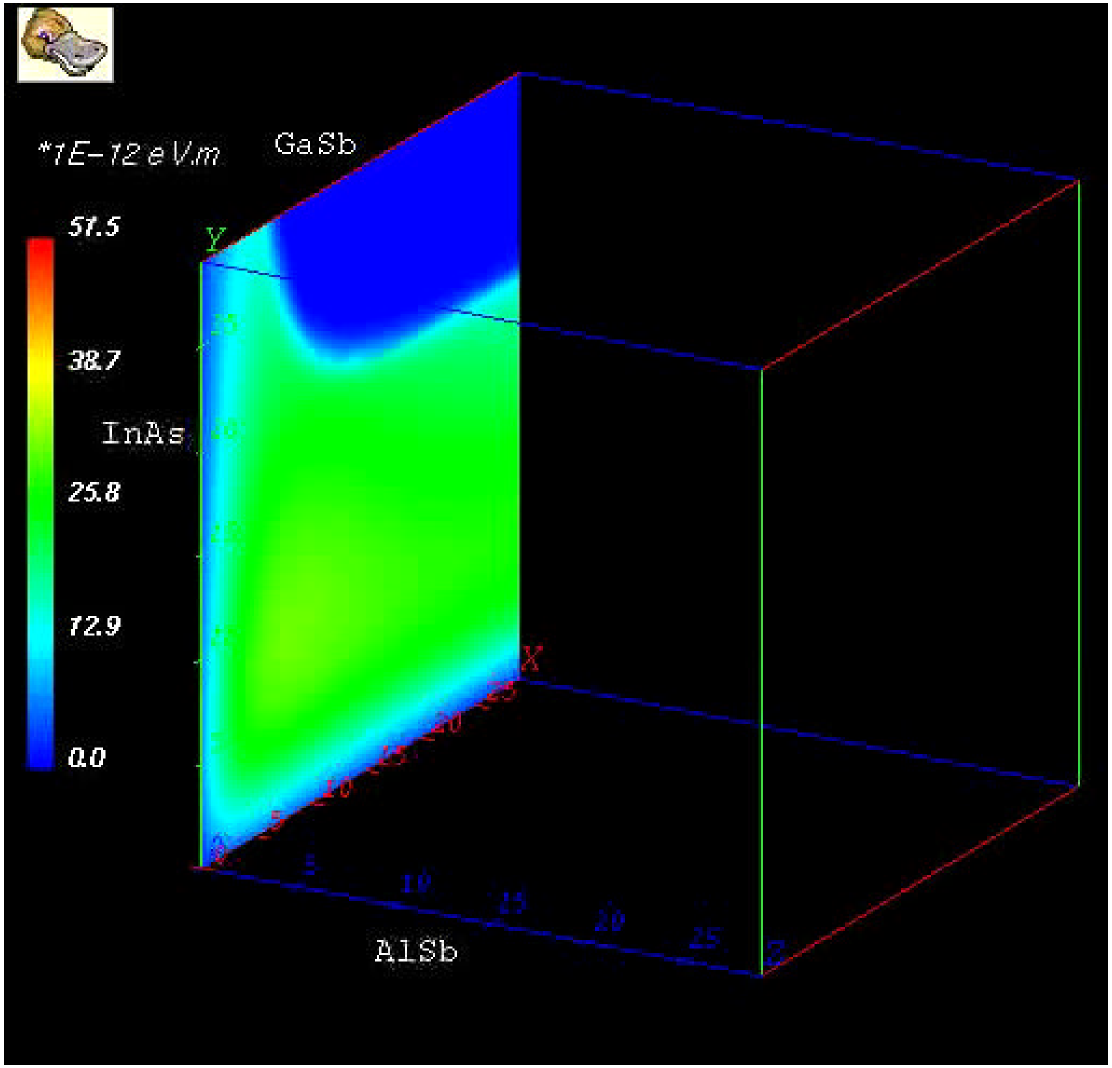


The size of the Rashba coefficient for each superlattice

α_R(J=InAs,K=GaSb, L=AlSb) is as four dimensional surface

Show Color Coded section thru the three dimensional J, K, L plane.

3D plot of the Rashba coefficient



Ways of Coupling to Rashba

- Electric Fields
- Magnetic Fields

Electric Field Induced Spin

No Electric Field

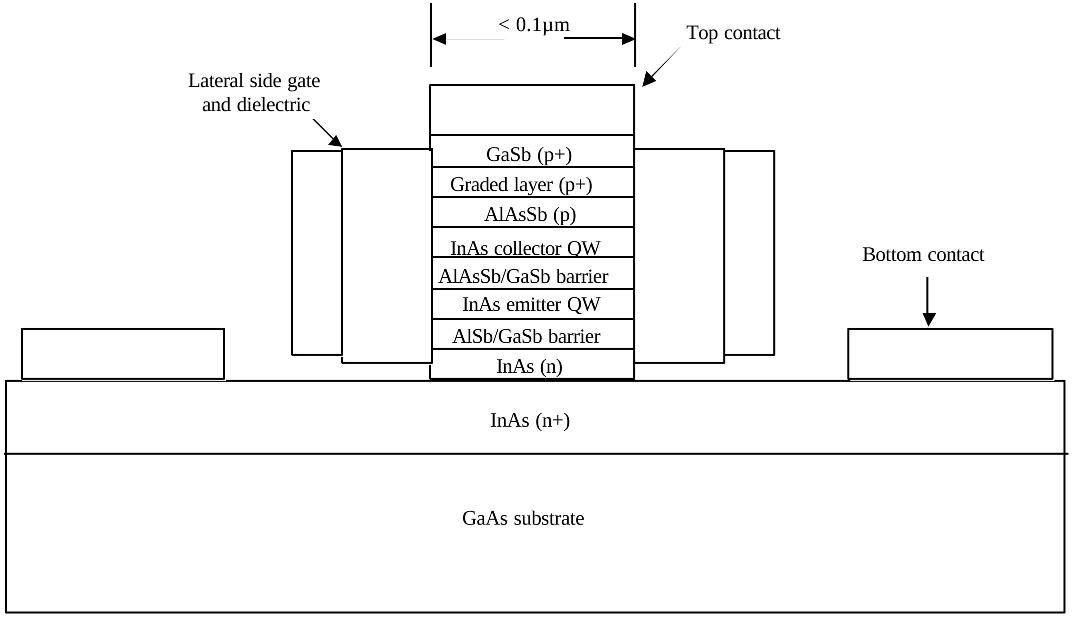
Shift in Fermi Sphere Due
Electric Field

Gives Net Spin

Lateral E-Field Diode

Lateral E-Field Resonant Tunneling Diode - Light Emitting Diode

- Hybrid RTD-LED structure:
  - Asymmetric RTD with lateral E-field for spin-polarized current
  - LED to faciliate detection of spin-polarization through optical polarization measurement.



D. Chow, HRL Laboratories.

Micromagnets

Energy= Exchange+Anistropy+
Demagnetizing Energy

$$\nabla \bullet \vec{B} = 0$$

$$\nabla \times \vec{H} = j_{external}$$

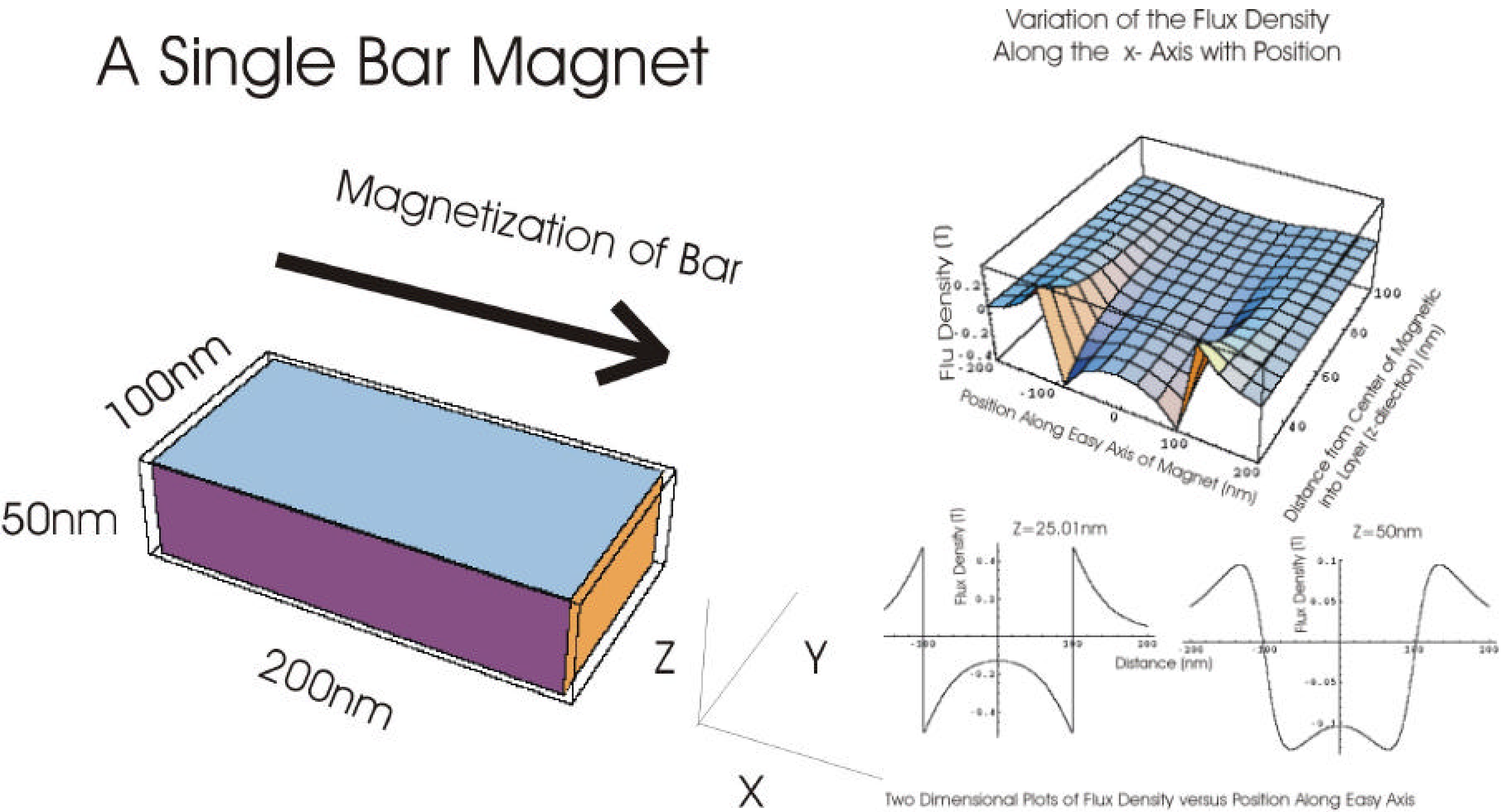
$$\vec{B} = m_0 \vec{H} + \vec{M}$$

$$\vec{H} = -\nabla f$$

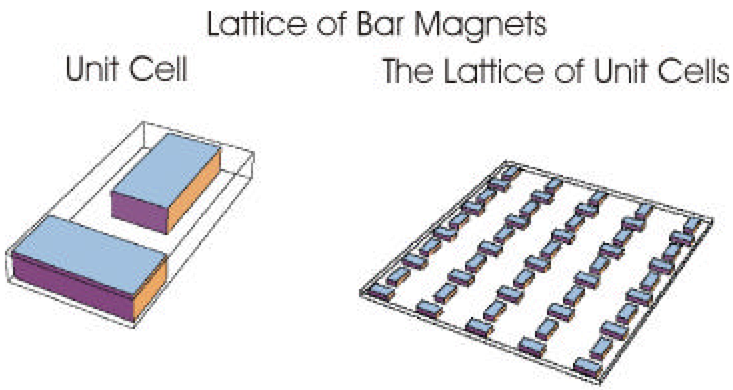
$$\nabla^2 f = \frac{\nabla \bullet \vec{M}}{m_0}$$

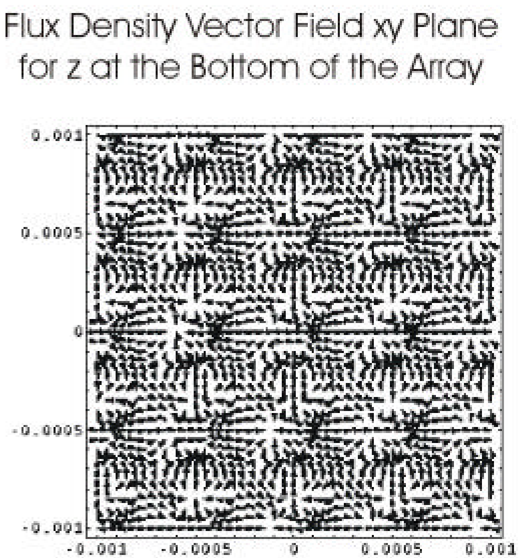
- Magnetization uniform typically
- Demagnetizing Fields Important
- Anistropy
  - Bulk
  - Surface/Interface

Magnetic Field Variation Around a Bar



Magnetic Field for Lattice of Nanomagnetics

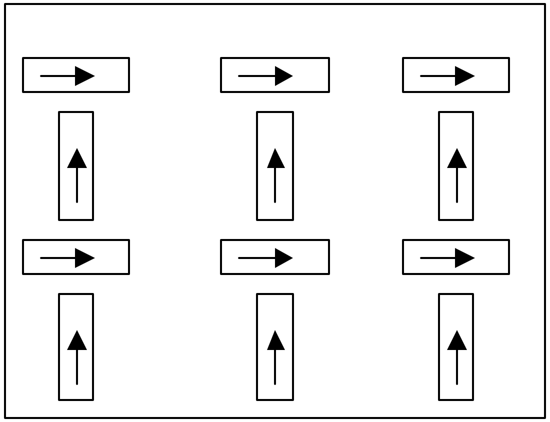




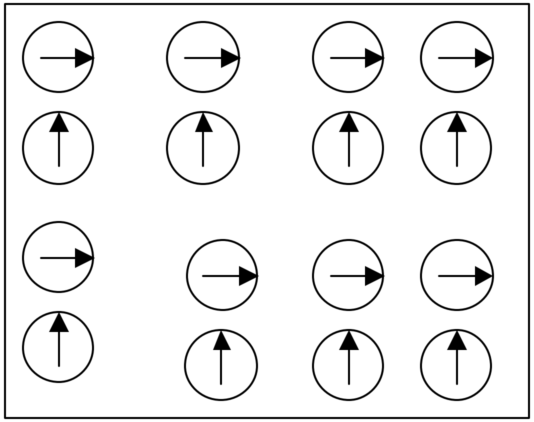
- Put down a periodic array of nanomagnets
- Gives periodic variation in magnetic field
- “Band Structure” Effects

Methods for Orienting Magnets

Shape Anistropy



Interface Anistropy



- Anisotropy Can Play a Major Role in Orienting Magnets
- Two Types
  - Shape
  - Interface

Stern-Gerlach Effect

$$\vec{F}_{Stern-Gerlacch} = \left(\nabla(\vec{S} \bullet \vec{B})\right)\left(\frac{2gm_B}{\hbar}\right)$$

$$\frac{dB}{dx} = \frac{2Tesla}{200\,nanometers}$$

$$g = 13$$

$$F_{Stern-Gerlach} = 1.21 \times 10^{-15}\ Newton$$

$$a_{Stern-Gerlach} = \frac{F_{Stern-Gerlach}}{effective\ mass \times electron\, mass} = 5.75 \times 10^{16}\ \frac{Meter}{Second^2}$$

The Numbers

$$Separation\ dis\tan ce\ \ for\ \ mean\ \ free\,time =$$

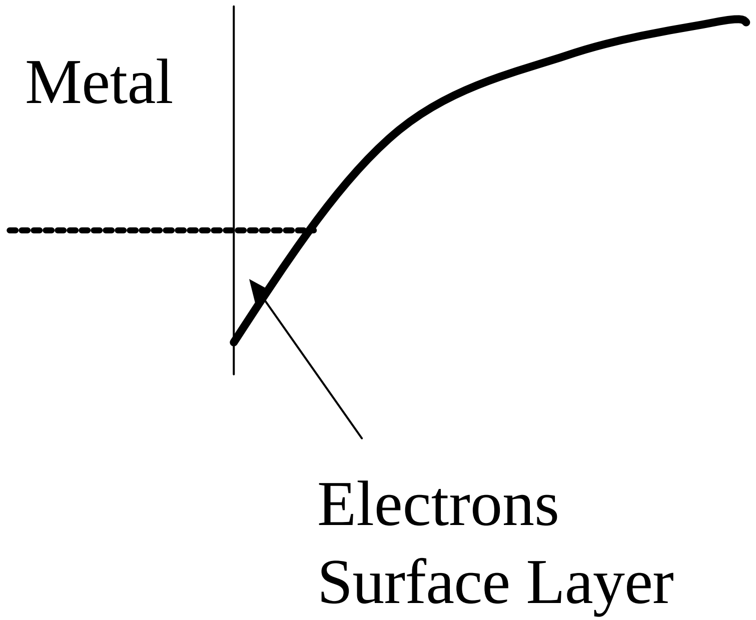
$$\frac{a_{Stern-Gerlach}\left(t_{mean\ free\,tme}\right)^2}{2} = 7.9nanometers$$

$$Separation\ dis\tan ce\ \ for\ \ spin\ \ relaxation\,time =$$

$$\frac{a_{Stern-Gerlach}\left(t_{spinn\,relaxation\,tme}\right)^2}{2} = 10.4mcirometers$$

Big Effect

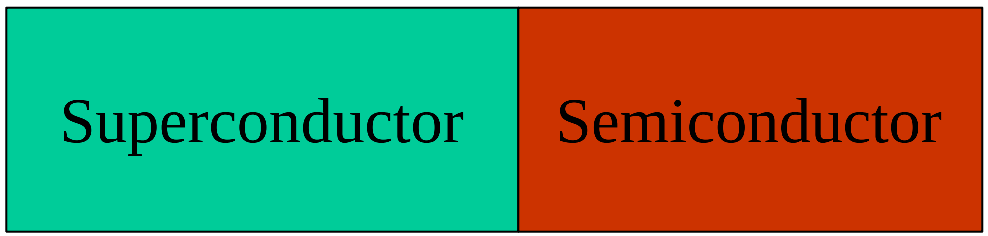
Proximity Effect Superconductivity



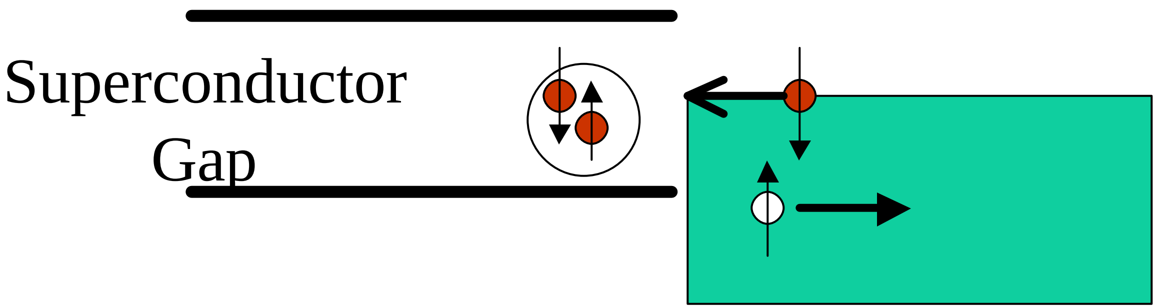
- Proximity Effect to Induce Superconductivity
- Thus Have Superconducting Channel in InAs
- This Can Be Exploited in a Number of Devices

Andreev Reflection Effect

A.F. Andreev, Zh. E´ ksp. Teor. Fiz. **46**, 1823(1964) Sov. Phys. JETP **19**, 1228 1964



- Coupling of Superconductor/(Metal, Semiconductor, Ferromagnet..) thru Interface
- Spin Pairing requirement yields information on spin polarization



Continuity of Current and Pairs in Superconductivity Requires

Applications of Andreev Reflections

- Produce Weak Link with Semiconductor
- Measure Spin Polarization
- Requires Coherence and Measures Coherence

Proximity Effect Jospehson Junction
H. Kroemer, C. Nguyen and E L. Hu
Inst. Phys. Conf. Ser 141 Ch. 1 (1994)

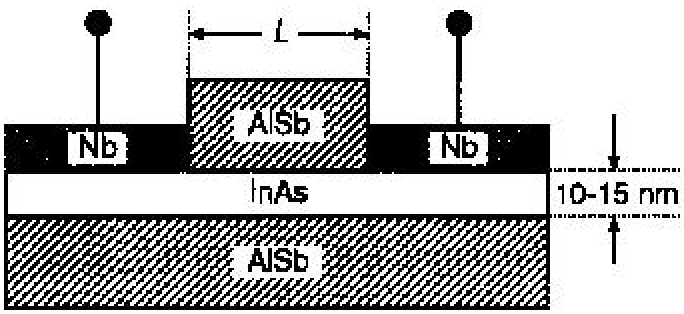


Fig. 1. Cross-sectional geometry of the basic InAs-AlSb quantum well structures employed in this work.

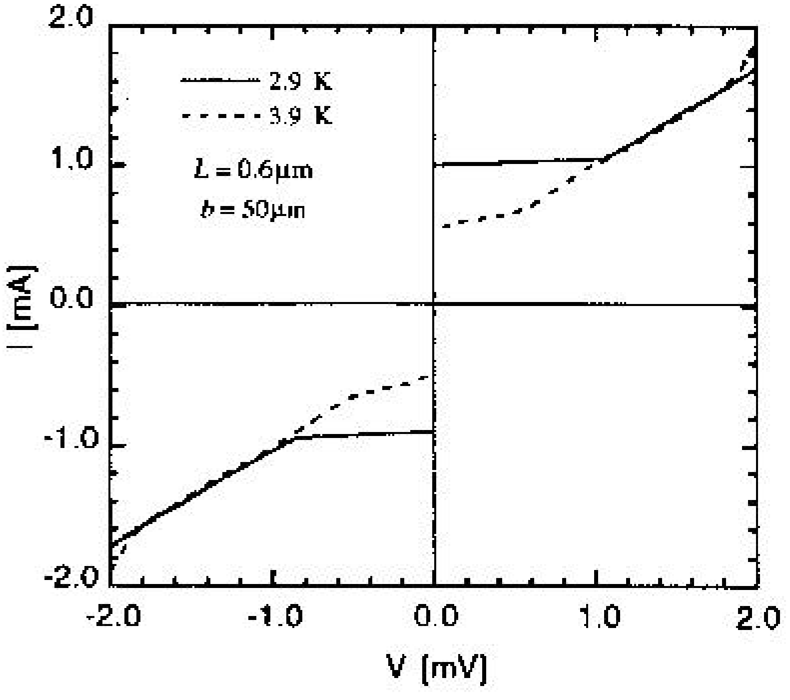
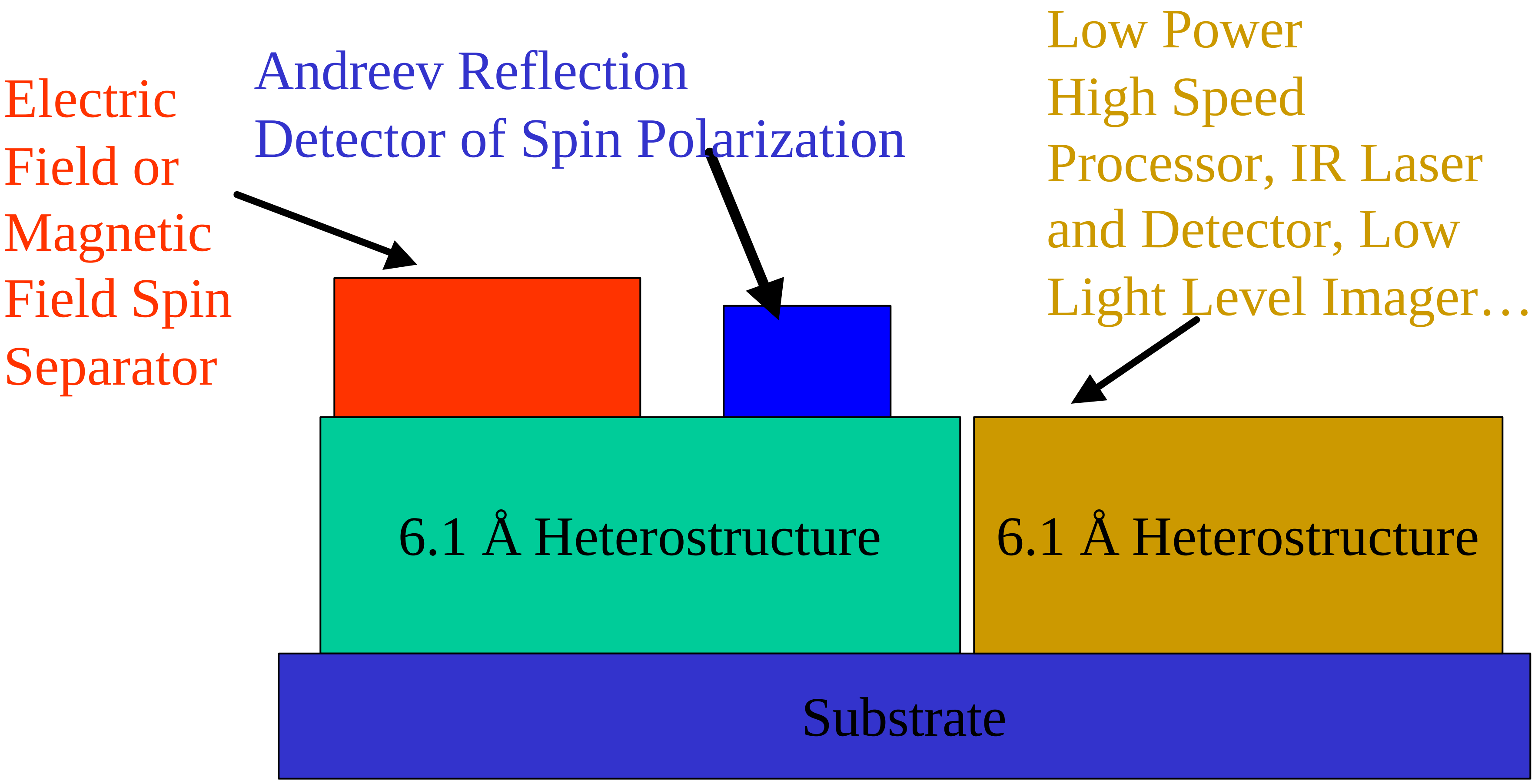


Fig. 2. Josephson-type *I-V* characteristics of a device with 0.6μm electrode separation, at two temperatures

Ultimate Device



The Best is Still to Come

- Combinations
  - Standard Device Physics
    - Detectors, Lasers
    - HEMT’s, HBT’s and RTD’s
  - New Device Physics
    - Spin Based
    - Superconductivity
- New Devices and Systems

Magnetic Therapy

Feel The Benefit Of Magnetic Therapy!

This attractive Shiny and 24K gold plated bracelet is embedded with powerful 1,800 + gauss magnets. Many studies have shown that magnets may be an effective, non-invasive, drug-free way to help reduce pain, to help increase flexibility and promote the body's own natural healing process. This newly designed bracelet feature deep penetrating uni-pole magnets. This type of magnet is believed to provide the superior results compared to the bi-polar magnets often used in other brands.

Magnetic therapy is a natural, non-invasive way to relieve the discomfort associated with the rigors of daily life. Bracelets are popular among professional athletes as therapy for aches and stiffness. Lightweight designed to be worn by both men and women.

This bracelet is 7 1/2" long and it comes in a beautiful Velvet Pouch for you to store when not in use.